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The Influence of the Position of Insulation Material in Wall on Dynamic Load

Haoran Ning[1], Xiaoli Hao[1,2*], Haiqiao Wang[1], Fangxing Chen[1]

[1]Hunan University of Science and Technology, Xiangtan, Hunan 411201, China
[2]Hunan Engineering Research Center for Intelligently Prefabricated Passive House, Xiangtan, Hunan, 411201, China
*Corresponding author: Tel: +86 13787429406; haoxiaoli2002@aliyun.com (X. Hao)

Abstract **-** It is well known that how to save energy in this era of energy scarcity has always been a problem that countries are constantly exploring. How to reduce building energy consumption is a hot spot, which has to mention the most important part of building envelope. The wall insulation is developing more and more rapidly in China. The energy consumption impact caused by the insulation material placement problem is worth considering. This paper analyzes the building energy consumption when the insulation material is placed in different positions of the wall through the building energy simulation software EnergyPlus. When the insulation material is placed on the outermost side of the wall, the load required for the building is the smallest, the peak heating load is the smallest, and the insulation effect of the insulation material is optimal. External insulation of the wall will become an indispensable part of the energy-saving building. Playing an important role in reducing national energy.

Keywords**:** Insulation material; Energy saving;Simulation; Dynamic load

1. Introduction

Building section: as a major section of China's energy consumption ratio, plays an important role on the sustainable development of the country. Today, with the increase of environment protection awareness and worry about the future energy crisis-how to reduce building energy consumption is a problem worth exploring. Then, the heat loss of the building envelope is serious, among it,the wall accounts for a large share. Therefore, the development of wall insulation technology and energy-saving materials will be the main realization of building energy conservation. The research and development, selection and use of wall insulation materials have a non-negligible impact on building energy conservation. The insulation of the building wall is divided into external thermal insulation system, external wall internal insulation system, and external wall sandwich insulation.

At present, Li [1] have systematically reviewed the application and researched status of building energy-saving insulation materials in China, he listed new materials such as polymerized polystyrene board, phenolic foam board , polyurethane foam and so on. Ding, et al. [2] summarized and analyzed the three insulation materials of rigid polyurethane foam (PUF), foam concrete (FC) and vacuum insulation board (VIP board). Hu et al. [3] studied the development of wall insulation materials from two classifications of organic and inorganic insulation materials. Zhu et al.[4] have also made some achievements in this regard.Gao, et al. [5] have recently developed a new type of inorganic thermal insulation material that utilizes perlite tailings, which not only has better thermal insulation properties, but also effectively solves the problem of solid tailings utilization. Tingley et al. [6] analyzed the insulation materials of the exterior wall insulation system, and these materials can also be used for internal applications. They used the life cycle method to estimate the environmental impact throughout the life cycle.They quantitatively compared the environmental impacts of several exterior wall insulation materials to find which exterior insulation material is the most energy-efficient and economical. Lachheb, et al. [7] have shown that the addition of waste coffee grounds (SCGs) to insulation materials can reduce the thermal load by up to 20%. Gounni et al. [8] evaluated the thermal and economic performance of a new insulation material made up of textile waste.Villasmil, et al. [9] proposed that thermal energy storage systems (TES) using thermal insulation materials have a significant contribution to improving energy efficiency and reducing costs.

However, most researchers focused on the development of new insulation materials or the technical optimization of existing materials. In this paper, dynamic load calculation and analysis are carried out from the common insulation materials placed in the wall. In the same room, several different insulation materials are selected, and the dynamic load with insulation materials placed on different surfaces of the wall are calculated at different time steps through Energy Plus ：energy simulation software to obtain under what conditions the load is the least, and seek out the best insulation material placement position, which will reduce building energy consumption, save energy demand, and provide a feasible road for sustainable development in China. which will have important guiding significance for construction and installation in buildings.

2. Building simulation information

2.1. Building description

This paper selects a model building of 4×4×3m in Changsha City, Hunan Province of china,where has the climatic feature of hot- summer and cold- winter . The building area is 16m^2. Its structure is shown in Figure 1 . It is also simulated in Nanjing, which is also located in the hot summer and cold winter area.

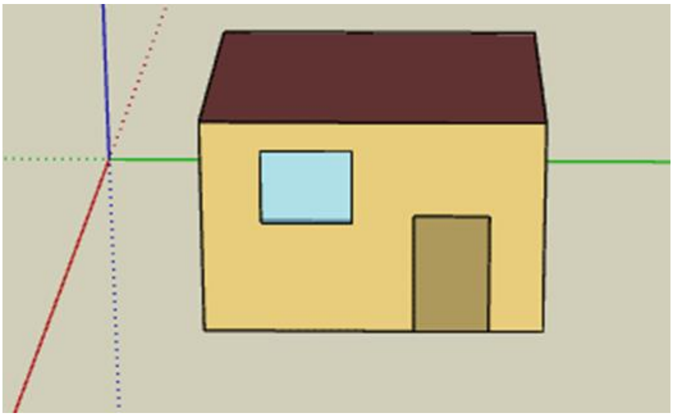

Fig. 1：Building model.

2.2. Building envelope structure

The thermal parameters of the external envelope structure of the simulated building are mainly selected according to the Public Building Energy Efficiency Design Standard(GB 50189-2015) [10] and Hunan Province Residential Building Energy Conservation Design Standard (DBJ43/001-2017) [11]. The dataset in the software EnergyPlus can provide the required wall, window and other materials, as well as the construction template with specific heat transfer coefficient. Users can customize the required wall, window and other materials according to the actual project, including its thermal conductivity, density, thickness and the specific heat, etc., you can also choose the pre-made template that comes from EnergyPlus [12]. The window of this study uses the custom template in the software. The wall insulation material is divided into four kinds of aerated concrete, cement expanded perlite, polyurethane and thermal insulation rock wool. Their main thermal performance parameters are shown in Table 1.

Table 1: Thermal performance parameters of insulation material.

Thermal insulation material	Conductivity (W/m·K)	Thickness（m）	Density（kg/m^3）	Specific heat (J/kg•K)
Aerated concrete	0.22	0.22	700	1150.8
Cement	0.055	0.06	500	753

expanded perlite				
PU	0.02	0.02	30	1465
Rock wool	0.03	0.03	100	750

2.3. Outdoor design parameters

The study selected two typical cities, Changsha and Nanjing, which belong to the hot summer and cold winter regions. It is a subtropical monsoon climate, with high temperature and rain in summer, wet and cold in winter, outdoor design parameters come from the EnergyPlus official website weather database [12]. The source is from CSWD（Chinese Standard Weather Data）, as shown in Table 2 and Table 3 .

Table 2: Outdoor design parameters in Changsha.

Items	Summer Design day	Winter Design day
Air conditioning outdoor calculation dry ball calculation temperature /℃	36	-1
Air conditioning calculation wet bulb temperature /℃	26.8	-
Barometric pressure/kPa	100.511	100.511
Outdoor mean wind speed/m/s	3.2	2.1
Wind direction	220	340

Table 3: Outdoor design parameters in Nanjing.

Items	Summer Design day	Winter Design day
Air conditioning outdoor calculation dry ball calculation temperature /℃	35.1	-4.8
Air conditioning calculation wet bulb temperature /℃	27.1	-
Barometric pressure/kPa	101.24	101.24
Outdoor mean wind speed/m/s	3.5	1
Wind direction	220	340

2.4. Indoor environment design parameters

According to the provisions of China's "Code for Design of Heating, Ventilation and Air Conditioning for Civil Buildings" (GB50736-2012) [13], the temperature range of air conditioning interior design parameters is 18-24 °C under heating conditions and cooling conditions, 24-28 ° C, respectively. Therefore, in the case of meeting national standards to choose the following data is conducive to energy conservation.

Table 4: Indoor environment design parameters in Changsha and Nanjing.

Room type	Winter temperature℃	Summer temperature℃	Winter humidity %	Summer humidity %
office	20	25	≥ 30	≤ 70

2.5. Indoor heat gains

The building's hot and humid environment is mainly affected by internal disturbances and external disturbances. The internal and external disturbance factors such as personnel, lighting, indoor equipment and ventilation are considered in this paper.

1) Staff settings. The personnel density is set according to the office 8m2/people. For the convenience of calculation, it is assumed that the activities of each personnel are the same.

2) Lighting settings. According to the above standard, in the calculation of building load, this room is rated according to the power density of $9W/m^2$ in the general office.

3) Electrical equipment settings. According to the above standard, in the calculation of building load, the electrical equipment power density is $5W/m^2$.

4) Ventilation settings. According to the above standard, the standard for fresh air volume should be $30m^3/h•p$.

3. EnergyPlus Energy simulation

The Energy Plus energy simulation software used in this article is a new generation of software developed by the US Department of Energy based on DOE-2 and BLAST software, with many new features [14].EnergyPlus is an energy analysis and thermal load simulation program, It has the following main features: 1) Simulation method of load / system / equipment using integrated synchronization.

2) When calculating the load, the time step can be adjusted at any time, and the time step can be customized to accelerate convergence.

3) Heat balance based solution technique for building thermal loads that allows for simulta-neous calculation of radiant and convective effects at both in the interior and exterior surface during each time step, the simulation results are more accurate.

4) Using CTF to simulate the transient heat transfer of walls, roofs, floors, etc.

5) Simulation of soil heat transfer using a three-dimensional finite difference soil model and simplified analytical methods.

6) Simulate the heat and moisture transfer of the wall with simultaneous heat and mass transfer models. Thermal comfort model based on parameters such as human activity, indoor temperature and humidity, etc.

7) Simulation of air-conditioning system with adjustable structure based on loop 8) Users can simulate typical systems without modifying the source program. Link with some commonly used simulation software, such as WINDOW5, WINDOW6, DElight, SPARK, etc., so that users can simulate the building system in more detail.

8) The source code is open, and users can add new modules or functions according to their needs[15].

3.1. Energy simulation time

This paper simulates the annual dynamic load of the entire building with a simulation duration of 8760hours, the simulation time is from January 1st 0:00 to December 31st 24:00 [16].The typical summer design day is July 21st, the winter typical design day is January 21st, the simulation time is 0:00 to 24:00 on July 21 and 0:00 to 24:00 on January 21.

3.2. Energy consumption simulation results

In this paper, four kinds of thermal insulation materials, such as aerated concrete, cement expanded perlite, polyurethane and thermal insulation mineral wool are selected. Each material is placed on the outermost side of the wall, the intermediate side of the wall and the innermost side of the wall. Taking aerated concrete as an example, the placement is as shown in Table 6.The placement of the other three insulation materials is the same.

Table 6: Insulation material placement.

Obj1	Obj2	Obj3
Exterior wall	Exterior wall	Exterior wall

G01a 12mm gypsum board	Aerated concrete220	G01a 12mm gypsum board
Composite morter 20mm	G01a 12mm gypsum board	Composite morter 20mm
M05 190mm concrete block Composite morter 20mm	Composite morter 20mm M05 190mm concrete block	Aerated concrete220 M05 190mm concrete block
Aerated concrete220	Composite morter 20mm	Composite morter 20mm

In order to further verify the obtained results and make the results more accurate, different time steps can be selected for calculation. The effects of the experimental results are analyzed under different simulation time steps. Here, the hourly time steps are set separately. Calculations were made for the conditions of 4 and 6, and finally the following data were obtained. The obtained load calculation results and energy consumption simulation results are shown in Tables 7, 8, 9, and 10.

Table 7: Calculation load with time step 4 in Changsha.

Insulation material setting	Air conditioning calculation total load (MJ/m^2)	Heating peak load（W）	Cooling peak load(W)
Aerated concrete:outside	904.30	2185.8	2869.93
Aeratedconcrete:intermediate	906.27	2188	2875.04
Aerated concrete:inside	907.71	2189.0	2921.75
Cement expanded perlite:outside	898.52	2157.7	2891.58
Cement expanded perlite: intermediate	899.90	2157.9	2885.76
Cement expanded perlite:inside	906.80	2158.7	2984.03
PU:outside	909.79	2186.8	2929.82
PU:intermediate	912.17	2188.9	2933.83
PU:inside	920.52	2189.6	3040.16
Rock wool:outside	909.63	2186.8	2928.03
Rockwool:intermediate	911.99	2188.9	2931.71
Rock wool:inside	920.31	2189.6	2995.7

Table 8: Calculation load with time step 6 in Changsha.

Insulation material setting	Air conditioning calculation total load (MJ/m^2)	Heating peak load（W）	Cooling peak load(W)
Aerated concrete:outside	905.31	2186.1	2875.64
Aeratedconcrete:intermediate	907.30	2188.3	2881.17
Aerated concrete:inside	908.64	2189.2	2924.73
Cement expanded perlite:outside	898.74	2157.9	2890.38
Cement expanded perlite: intermediate	900.09	2158.2	2884.56
Cement expanded perlite:inside	905.95	2158.9	2983.22
PU:outside	910.09	2187.1	2928.75
PU:intermediate	912.42	2189.2	2932.10

PU:inside	919.21	2189.8	3040.09
Rock wool:outside	909.87	2187.1	2926.97
Rockwool:intermediate	912.25	2189.2	2929.99
Rock wool:inside	919.08	2189.8	3037.72

Table 9: Calculation load with time step 4 in Nanjing.

Insulation material setting	Air conditioning calculation total load (MJ/m^2)	Heating peak load（W)	Cooling peak load(W)
PU:outside	933.93	2543.4	2921.14
PU:intermediate	934.24	2544.4	2926.22
PU:inside	947.19	2545.1	3031.06
Rock wool:outside	933.75	2543.4	2919.32
Rockwool:intermediate	933.98	2544.4	2924.06
Rock wool:inside	946.90	2545.1	3028.58

Table 10: Calculation load with time step 6 in Nanjing.

Insulation material setting	Air conditioning calculation total load (MJ/m^2)	Heating peak load（W)	Cooling peak load(W)
PU:outside	934.37	2543.7	2920.27
PU:intermediate	934.67	2544.6	2925.69
PU:inside	946.36	2545.3	3030.52
Rock wool:outside	934.17	2543.7	2918.44
Rockwool:intermediate	934.42	2544.6	2923.51
Rock wool:inside	946.14	2545.3	3028.08

Taking cement-expanded perlite as a typical example, the following is a graph of the annual dynamic load calculation of cement-expanded perlite with a time step of 4.

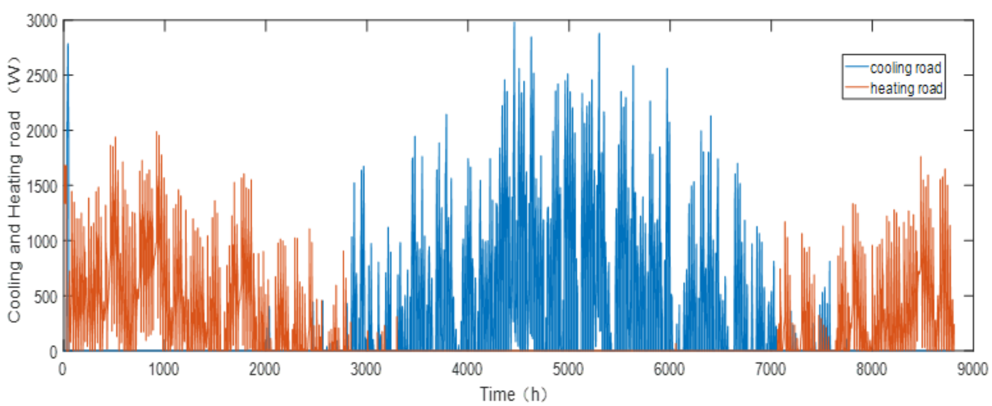

Fig. 2: Annual cooling and heating load on innermost side of cement expanded perlite with time step of 4.

In order to more intuitively obtain the dynamic load change of the insulation material load under different placement conditions, the dynamic load analysis is taken for the winter design day January 21 and the summer design day July 21 as the typical day, the following is the heating and cooling load calculated by the cement expanded perlite in the time step of 4.

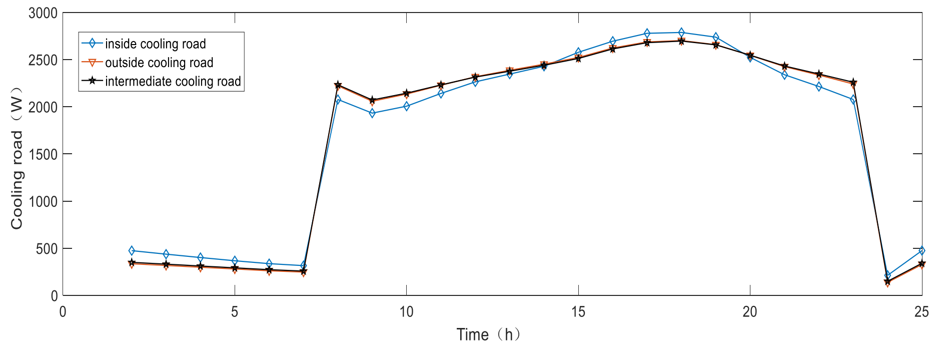

Fig. 3: Cooling load in summer under three placements of cement expanded perlite in typical day.

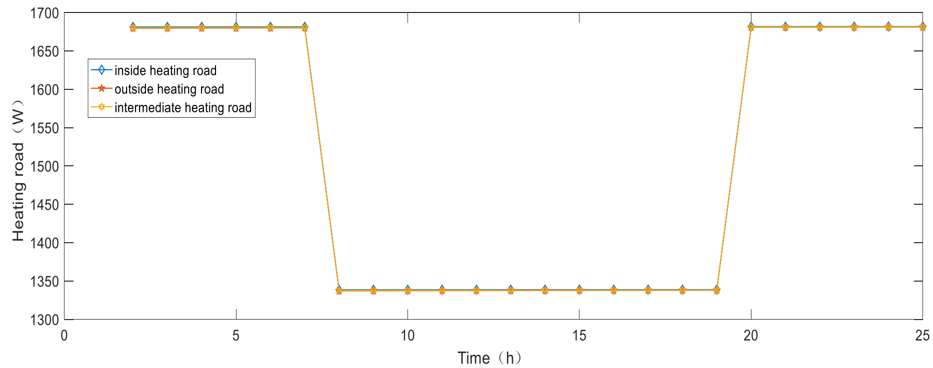

Fig. 4: Heating load in winter under three placement conditions of cement expanded perlite in typical day.

3.3. Analysis of energy consumption simulation results

This article studies the effects of different types of insulation materials placed on different positions of the wall on the dynamic load of cooling and heating throughout the year. It adds four kinds of common thermal insulation materials, such as aerated concrete, cement expanded perlite, polyurethane and rock wool to the building wall of Changsha City. The calculation load with a time step of 4 is shown in Table 4. The calculation load with a time step of 6 is shown in Table 5. The calculation results of Nanjing are shown in Tables 9 and 10. The cement expanded pearl with a step size of 4 is selected. The annual dynamic thermal load of the rock is shown in Figure 2. The typical cold and heat load of the cemented perlite with a step size of 4 is shown in Figure 3-4.

For the convenience of the following description, this article deliberately places the innermost, outermost, and intermediate sides of the placement position with a, b, and c. From the calculation results of Changsha, Tables 4 and 5, we can obtain when the thermal insulation material is placed at position b. Whenever the calculated step size is 4 or 6, the load is significantly smaller than that placed in a and c. When the step size is 4, the material is placed at a small gap between b and c. Aerated concrete and cement expanded perlite are placed. The load at b is 1.97 MJ/m^2 and 1.38 MJ/m^{2}less than that of c, while the polyurethane and mineral wool b are 2.92 MJ/m^2 and 2.36 MJ/m^2 less than c. The load placed on the insulation materials at a and c are greater than the energy consumption at b. When the calculation is more accurate at a time step of 6, the energy consumption of the four materials b, such as aerated concrete and cement expanded perlite, is less than a, which is 3.33 MJ/m^2, 7.21 MJ/m^2, and 9.12 MJ/m^2, respectively. The same results can be obtained from Tables 9 and 10.

It can also be seen from the table that when the insulation material is placed at different positions, the peak cooling load and heating load of the three materials are also different. The aerated concrete is placed at a and b with a step size of 4 and 6 calculated peaks. The heating and cooling load is smaller than that placed at c, which is smaller at b. The peak thermal and thermal load calculated by the cement expanded perlite at steps 4 and 6 is smaller at b than at a and c, and the same results as for aerated concrete are obtained.

From Figure 2, the verification conclusion can be obtained. From Figure 2, it can be obtained that the graph of the annual hot and cold dynamic load is similar when the different materials are placed at different positions, but when the insulation material is placed on the outside.The maximum cooling load is obviously smaller than when it is placed in other locations. During the period when the building needs cooling, it can be seen from the figure that the area with a larger cooling load value is less than other locations.

In order to further confirm the conclusions obtained, we select a dynamic load of two days of typical design day of cement-expanded perlite in the winter and summer seasons with a step length of 4. As shown in Figure 3-4, we can see from the figure that although the thermal load changes when the insulation materials are placed at different positions, the cooling load still has a slight difference, we can obtain that when the insulation material is placed at b. Its curved section is at the bottom, indicating that the cold load is smaller than that placed at both a and c.

Finally, we can find that the calculation load obtained when cement expanded perlite is used as building insulation ma terial is the smallest, especially when placed at b, the calculated load is less than that of the other three insulation materials, and the maximum is less under the calculation conditions of steps 4 and 6.Max_{AC}=10.12MJ/m^2 ,Max_{PU}=22MJ/m^2, Max_{RW} =21.79MJ/m^2。

Take the use of insulation material PU in Nanjing as an example of calculating a step of 4, the heat flux density about inside and outside of the west wall is analyzed. The accuracy of the above results can be verified from the following figure.

It can be seen from the above pictures that the heat flow density of polyurethane when placed on the outside of the wall is the minimum in all four walls, and the heat flow of the insulation material placed on the outermost side is the smallest.

The heat exchange of the wall is carried out. We do not consider the dynamic influence.In the steady heat transfer process, the heat flux is the same at different locations when the heat transfer coefficient K is the same. However, when we consider the dynamic influence, the two coefficients of ρ and Cp of the thermal insulation material will affect the result. Comparing the four temperature coefficient $a=\lambda/\rho c$ can be obtained,$a_{AC}=2.73\times10^{-7}$ m^2/s、 $a_{CEP}=1.46\times10^{-7}$ m^2/s、 $a_{PU}=4.55\times10^{-7}m^2/s$、$a_{RW}=4\times10^{-7}m^2/s$, Cement expanded perlite has the smallest value .Cement expanded perlite has the lowest temperature coefficient. The insulation material placedon the outside is better than other locations, which can effectively avoid the occurrence of hot and cold bridges[17].

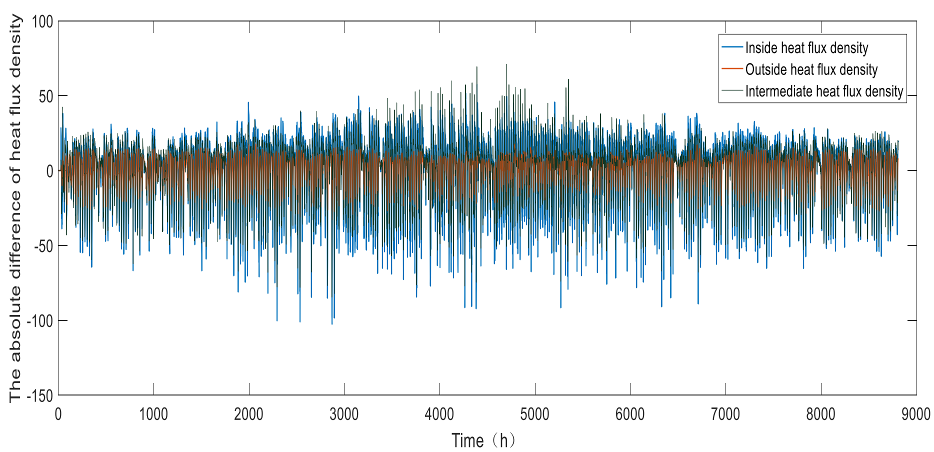

Fig.7：Absolute difference in heat flux density between inside and outside of the Western Wall.

3.4. Verification

In order to verify the above simulation results, this article refers to Meral Ozel's analysis of insulation material placed at three different locations in a south wall in Turkey, the implicit finite difference calculation is used to find that the peak load and temperature amplitude of summer and winter occur most in the intermediate insulation, and the smallest occur in the external insulation of the wall[18]. S. A. Al-Sanea also found that for all wall orientations, the outer insulation layer can provide smaller load fluctuations and smaller peak loads in summer and winter through numerical simulation[19]. Saleh MAE analyzes the use of wall insulation materials in hot and dry areas, and proves that when the thickness of the building's external insulation layer is 5-10cm, the effect of reducing the total cooling and heating load is the best. By adding insulation on the outside of the building wall, the heat loss of the building can be significantly reduced, and extend the time required to reach thermal equilibrium when the external temperature changes[17]. When the insulation material is placed on the outside only when the outer insulation thickness reaches a certain value, best load levelling (which is consistent with minimum capacity or cost of the air-conditioning plant) is achieved[20], From these documents, we can find that the energy consumption results simulated by EnergyPlus have a reference value, and show that the simulation results are correct.

4. Conclusions

In this paper, the influence of dynamic load on three different insulation materials placed in different positions of the wall is analyzed, and different calculation durations are set to prove it, the following conclusions are obtained.

1）The insulation material placed on the outside is better than the insulation on the inside and the intermediate layer. The heating and cooling load required to be placed on the outside is less than the other two conditions, which is more conducive to energy saving, especially when the specific heat and density of the insulation material. Especially when the specific heat and density of the heat insulating material is relatively small, the energy saving effect is more remarkable, and the energy consumption of the demand is less.

2）The peak cooling and heating load of the insulation material placed on the outside is less than that of the other two locations. The daily standard deviation between the heating load and the heating load during the working day is smaller, which also can be adapted to the cooling load,and the thermal insulation effect is more stable.

The insulation material placed on the outside of the wall has a good reference for the selection of the placement of the insulation material. It is not only conducive to energy conservation in the engineering practice, but also has practical significance for reducing energy utilization in China,it can extend the life about the main body structure of the wall.With the advantages of avoiding excessive thermal bridges and other merits, the external insulation of the wall will play an important role in the reduction of building energy consumption in China.

There are some shortcomings in this experiment: one is that no specific experimental verification has been obtained, and no specific test treatment is applied to the calculation of building load. Secondly, the difference between the north and the south of China is large, and different weather conditions in different regions may have an impact on the results. In the end, the density of the insulation material is large and the density of the wall is not much different. The lightweight materials should be considered more,Next, we will consider these one by one to get more accurate results.

Acknowledgements

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